OTWELL

Design, Construction and Testing of a Thermal Regulator

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THE DESIGN, CONSTRUCTION AND TESTING OF A THERMAL REGULATOR

BY

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INTRODUCTION.

A thermal regulator or thermostat is a device for maintaining a constant temperature in a bath of some fluid as air, water, a salt solution or oil. There are various scientific operations which require a reasonably constant temperature. In physics many phenomena change with the temperature and some rapidly, as the resistance of electrolytes. Hence if accuracy is required the temperature must not be allowed to change while the measurements are being made.

In chemistry especially the physical division of this science nearly all measurements in density, conductivity, velocity, reaction, refraction of liquids etc. must be made at a given temperature.

The biologist, too, finds that the rate in which certain activities proceed is strongly influenced by the temperature, and that a means of keeping this constant is necessary.

The commercial applications include among others, incubators, cold storage etc. There are two general principles upon which thermostats depend:

I. More heat is supplied than needed and the excess removed at constant temperature.

This method is most often realized in practice by taking advantage of the fact that certain changes in the state of aggregation of substances take place at constant temperatures.

The melting point of ice is frequently employed as it is easily produced and maintained. The object to be kept at 0° must be embedded in snow or pounded ice. These must be pure as all soluble substances lower the freezing point. The water must be removed as melt-

ing progresses or the temperature will be above $0°$ unless vigorously stirred. Since it is difficult to obtain other substances pure and in large quantities, none have come in general use for maintaining the temperature of their freezing points. In this connection, however, De Visser's acetic acid calorimeter might be mentioned. (1)

Since the addition of a foreign soluble substance lowers the freezing point, this suggests a method of obtaining temperatures lower than $0°$ with ice. In a mixture containing 26% of NaCl the freezing point is $20°$. By varying the percentage of salt from 0 to 26%, temperatures ranging from $0°$ to $-20°$ may be secured. Only rough results may be secured, thus, as melting changes the concentration. The addition of the proper amount of the hydrate $Fe_2Cl_6,12H_2O$ to ice yields a temp. of $-55°$.

Transition points have also been suggested as a means of securing reference points in calibrating thermometers etc. When the hydrate $Na_2SO_4\,10H_2O$ is heated slowly it will change into the anhydrous form at $33°$. At this temp. the hydrate and the anhydrous salt are in equilibrium with each other just as ice and water are at $0°$ and 76 c.m.

The boiling points of liquids give us a whole series of constant temperatures. The liquid to be kept boiling is generally placed in a vessel provided with a return condenser. The body to be maintained at constant temp. may be subjected to the direct action of the vapor, or it may be placed in an air or liquid bath immersed in the boiling liquid. Suitable liquids with their boiling points are the following: Carbon bisulphide $46°$, ether $34.9°$, ethyl alcohol $78°$ chlorbenzine $132°$, Bromb enzine $155°$, aniline $184°$, methyl salicitate $222°$,

1 Numbers in bibliography.

Bromomonopthalein 280°, mercury 358°. The obvious limitations of the use of boiling points of liquids for constant temperatures is their dependence upon the barometer. The pressure may be automatically regulated as Pomplum (3) and Ramsey & Young (4) have done.

The boiling points of liquids may be changed within slight limits by the addition of foreign substances. This method gives good results only when liquids closely related chemically are used.

A device by Prof. Crew (5) gives a temperature that is constant within about $\frac{1^\circ}{100}$. A vessel surrounded by wires heated by a constant current and the whole is placed in a vessel kept at 0° by ice packed between its double walls. The heat from the current increases till its is just balanced by loss from radiation to the ice.

II. The second class comprises those forms in which the heat is supplied as needed by an automatic regulator. Here changes in temperature set in action a process which varies the supply of heat. Theoretically this class has the disadvantage that the change must first occur before the regulating apparatus acts, and hence an oscillating rather than a constant temperature is produced. Practically the range may be made indefinitely small and this condition may answer all the requirements of a perfectly constant temperature.

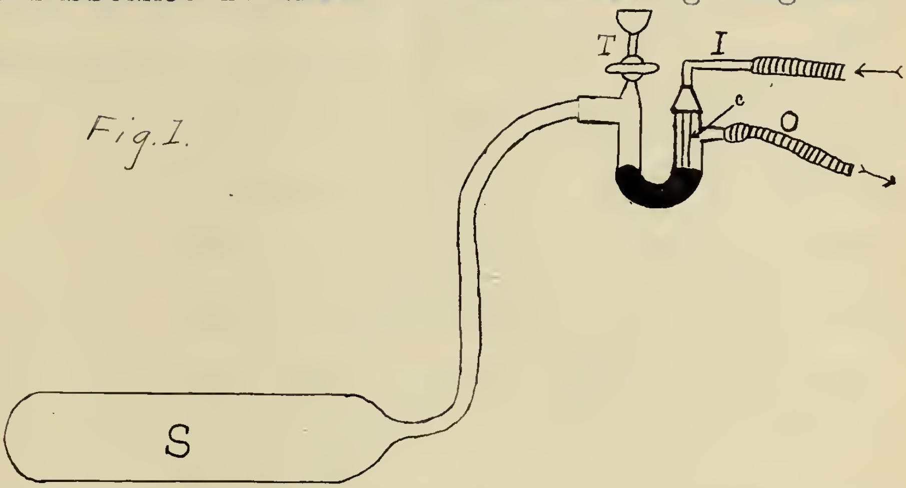
The heating of the air or liquid bath may be done by a gas supply, oil lamp or electric current.

In all the ordinary forms of temperature regulators a variation of temperature causes a substance to expand or contract and this action starts the regulating process.

A gas makes a very sensitive expansible substance, and were it not for the considerable variation in pressure due to changes in the barometric height, this would leave little to be desired.

The general form of regulating apparatus where a gas or liquid is the expansible substance is shown in the following diagram:

Fig. I.



S is a vessel preferably thin-walled which contains the expanding substance, gas or liquid. This is put in the place where a constant temperature is to be maintained. It is connected to one end of a U-tube in the bend of which mercury is contained; the other end of which has an inlet tube I and an outlet tube O. The inlet tube is cut off at right angles to the axis so that when expansion causes the mercury to rise, the gas supply is cut off. In order that the flame may not be extinguished a minute hole is made at C on the side of the outlet tube so that the current of gas may still flow when the mercury column rises. The same end may be attained by inserting a branch tube provided with a screw clip between the inlet and the outlet tubes. To adjust the regulator allow the tap T to remain open until the required temperature is attained and then close it making the minor adjustments by varying the position of the inlet tube.

This form of regulator depends to a considerable extent upon a strong gas pressure. For obvious reasons the bulb S should be as large as practicable.

With vapor regulators, on the other hand, the vapor chamber may be made very small, since the pressure of saturated vapors depends only upon the temperature and not on the volume.

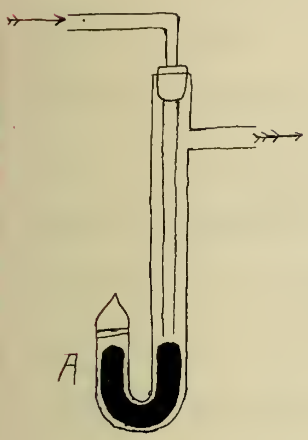


Fig. 2.

The general form of this style of regulators is shown in Figure 2. The liquid whose boiling point must be at the desired temperature, is put in at A and the point sealed off when the vapor is passing off so rapidly as to exclude all the air. According to Andreae (6) the temperature may be kept constant to within .04 or .05. Since the apparatus is very simple a whole series of these regulators may be made. Suitable liquids for the purpose are water, ethyl alcohol, methyl alcohol, ether and acetone.

These regulators in common with gas regulators depend upon changes in the barometer and hence they will not maintain a constant temperature for a long period.

Since the volume of a liquid is practically independent of the atmospheric pressure, liquids are much to be preferred as the expansible substances when the temperature is to be maintained constant for a long period. As the coefficient of expansion of liquids is smaller than that of gases a considerable quantity must be taken to secure the desired sensitiveness.

Water is a very unsuitable liquid to use as its coefficient of expansion is very small. A 10% solution of $CaCl$ is recommended by Ostwald, (7) as it expands much more than water and is not difficult to keep from escaping. Ether, alcohol, petroleum, toluene, and xylene

are highly expansible but have a vicious tendency to escape at the junctions of the apparatus.

The expansible substance may be a solid in which case the apparatus is much simplified as no containing vessel is required. The sensitiveness is of course much less than in the previous forms as solids expand less than liquids. A simple type of this class is given by Ostwald (7) in which a zinc rod is made to cut off the gas supply by expanding and pressing a disc upon the gas inlet tube. The apparatus is only useful for a regulation of $\pm 5^{\circ}$. Obviously such forms have an advantage only at such high temperatures as would make it inadmissible to employ more sensitive regulators.

Ostwald (7) has suggested that this form may be made more sensitive by the use of a combination of two metals of widely different expansibility put together in a spiral form and regulated by electromagnetic means.

A method of regulating the heat produced by a kerosene lamp is used by some makers of incubators. One form (9) has the expansible substance in a long tube extending throughout the incubator and ending in a U-tube containing mercury. A change in the level of the mercury moves a lever which in turn is connected to a system of two other levers and the motion thus magnified is made to move a disc up and down over the chimney of a lamp thus causing the heat given out to vary. It is claimed that the temperature by this means may be kept constant within a fraction of a degree Fahr.

In many respects an electric current possesses the advantage over other methods of heating. It is clean, easily controlled and the regulating apparatus may be made very quick and accurate in its action.

Mr. Chas. Knipp (8) has described a copper-iron thermostat designed to regulate the temperature of an air bath heathed by an alternating current through coils of wire. It gives a regulation of $\pm 1^{\circ}$ from room temperature to 380°.

When a current of electricity passes through a conductor, heat is developed according to the equation- $U = C^2Rt \times 0.24$ where U is the heat in calories, C the current in amperes, R the resistance in ohms, and t the time in seconds. The current may be sent through wires immersed in an oil bath or it may be sent through a salt solution. In the latter case an alternating current must be used as the polarizing effect of the current going in one direction will be neutralized by the current flowing in the opposite direction.

The following is an account of a thermostat which was designed by the writer and made under the writer's direction in the physical laboratory of the University of Illinois. First will be given a description of the thermostat with an account of its operation, and then the result of the preliminary test will be given with a discussion of the same.

AN ELECTRIC THERMOSTAT

This apparatus belongs to the second class of thermal regulators. The different parts are: the vessel containing the liquid to be heated; an arrangement for heating this liquid by means of an electric current; the regulator consisting of a system of copper tubing or "thermal bulb", holding a highly expansible liquid, in connection with a U-tube filled with mercury and the electrical connections for controlling the heating circuit; and finally the stirring device.

The general plan of its operation is as follows: The alternating current from the line circuit at a pressure of 110 volts is sent through wires immersed in an oil bath in one case and through a weak solution of common salt in the second instance. The current may be employed both to heat the bath and to maintain the temperature. When the adjustment is made, an increase of temperature will cause the liquid in the thermal bulb to expand, push the mercury up so as to make contact with a platinum point thus closing a circuit containing a relay which in turn opens a circuit containing an electromagnet that breaks the heating circuit.

Construction of the Different Parts.- The vessel containing the salt solution is cylindrical, 55 cm. deep. Two large sheet zinc electrodes, bent in the form of an arc to fit the sides of the vessel are placed opposite each other and connected to the 110 volt light circuit.

The vessel containing the oil bath, shown in figures I - IV# is a zinc-lined poplar box 45X45X50cm. inside measure provided with

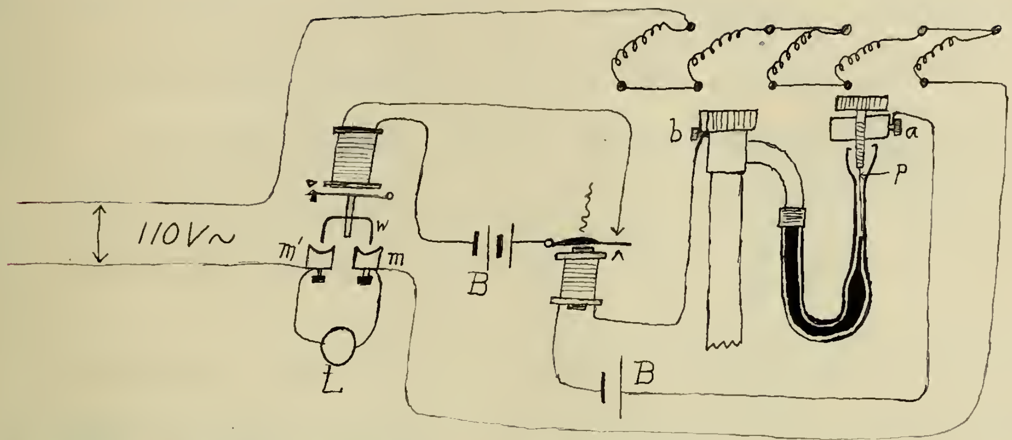
#Roman numerals refer to plat figures, Arabic numerals to text figs.

a close-fitting lid. The latter has a square hole which is closed in turn by a second lid having circular orifices for the thermometers. On the front of this box are two shelves for the relay,battery cells and other electrical apparatus for the regulatöng device. Above these is the switch board.

The heating is done by sending a current through bare iron wires wound on a square frame immersed in paraffine oil with which the box is filled. The frame is nearly as large as the inside of the box and it is kept from contact with the zinc by triangular blocks at the corners. The wires have a diameter of .35 mm. and a resistance of about 2 ohms per meter. They are wound in five sections of approximately 25 ohms and the terminals are carried to the switch board. The sections may be put in parallel, in series or any combination of these two. The current may easily be calculated from the resistance in any arrangement. For instance when all are in series the current is .88 amperes; all in parallel gives 22 amperes, 3 in parallel and 2 in series gives 2.9 amperes,etc.

The thermal bulb is placed inside the wire frame and rests on two strips secured to the bottom. It consists of two squares of sheet copper tubing one above the other and joined by three vertical tubes, the whole forming a closed system. A short vertical tube joined to the upper square is connected to a smaller upright,thick-walled brass tube which carries near the end a three-way joint and terminates in a brass screw cap C fig.VII. A smaller brass tube passes out laterally and bending down is joined to a U-tube of glass which is drawn out at a,fig. VII so that it has an inside diameter of about .7 mm. The joints of the copper tubing are heavily soldered and the corners are reinforced by placing strips over the seams and

soldering them down. The glass tube is joined to the brass tube as shown in fig. VII A. Above the glass tube is a brass block holding a thumb screw carrying a fine platnium wire. This block and the wire from the brass tube are both provided with binding posts. Mercury is poured into the glass tube till it rises above the lower end of the brass tube. A base board is secured to this part by three clips.



As shown in the above diagram the heating current goes through the wire coils (or through the salt solution), thence to the mercury contact m. Here an incandescent lamp is joined in parallel with a bent wire w to the mercury contact m' to which the line wire is connected. The wire w is attached to the lever of a sounder and it closes the heating circuit only when the armature is drawn down. Two Leclanché cells are used to operate the sounder circuit which is opened and closed by a relay having the platinum and ebonite contact points interchanged so that the sounder circuit is broken when the relay circuit is made. The wires from the latter pass to the binding posts a and b and the rise of the mercury column closes the circuit. In order to avoid the spark at break the binding posts a and b are joined by a very high resistance conductor so that there is a current flowing all the time though it is not strong enough to operate the relay.

The stirring device as shown in fig.VIII consists of four paddles one being secured to the center of each upper strip on the frame for carrying the wires. They are made to swing in a vertical plane between the heating coils and the thermal bulb. A brass rod from the end of each passes through a slit in the lid and is joined to a cord passing around four small horizontal pulleys as shown in fig.III. At one corner of the lid is fixed a vertical pulley having a connecting rod joined to one of the paddles, and by turning the pulley the paddles are rotated through about 60°. A fan motor making 1600 revolutions and geared down to about 30 is used to operate the stirring device.

OPERATION.- The bath is heated up to the desired temperature by sending a current through the salt solution or through the wires immersed in oil. When the temperature required is much above that of the room,it is convenient to heat the solution or oil by means of a gas flame. If the current is not strong enough to heat the solution or maintain it at the proper temperature,a little salt may be thrown in to increase the conductivity. In case the current is too strong a rheostat may be put in series with the line circuit or tap water may be put in to replace some of the solution removed. It was found that ordinary tap water is a very fair conductor and little salt is needed to give ample conducting power to the solution. With the large electrodes used the resistance of a volume of water nearly filling the cylindrical vessel was only about 55 ohms.

With the wires in the oil bath the current may be given various values from 1 to 22 amperes by varying the resistance.

When it is desired to set the regulator at a certain temperature the cap c in fig. VII is unscrewed and the bath allowed to heat up

to nearly the desired temperature, then after filling it up flush with alcohol the cap is screwed down and the minor adjustments are made by raising or lowering the platnium point p, fig. VII.

When the temperature rises the alcohol in the thermal bulb expands pushing up the mercury column at a thus making contact with the platnium point. This closes the relay circuit, opening the sounder circuit, either cutting out the heating circuit altogether or reducing it by sending it through an incandescent lamp.

DISCUSSION.- We may easily calculate the smallest increase in temperature that will cause the regulating device to cut off the heating current. The volume of the thermal bulb is approximately 3200 cc. The cubical coefficient of expansion of alcohol is about .001122 while that of copper is .0000513. The net expansion of the alcohol is thus .0010707. An increase of 1° would thus give a volume increase of 3.4264 cc. Assuming the inside diameter of the glass tube at a fig. VII to be 1 mm. and a rise of 1 mm. necessary to make contact with p, it is seen that the current will be cut off with an increase of volume of .0007854 cc. This volume increase will be given by a temperature increase of $.0007854/3.4264 = 1/4360^{\circ}$.

The rapidity and closeness of regulation depends very largely, however, upon three other factors: (1) the efficient circulation of the heated liquid in the bath, (2) the quick response of the liquid in the thermal bulb to temperature changes, (3) the rate of conduction of the heat to the interior of the thermal bulb.

A more efficient circulation of the heated liquid might be secured by having the lateral strips on the paddles 1,1, fig. VIII set so that they are not perpendicular to the plane of motion. This would be more effective in forcing the heated liquid towards the

center. A form of stirrer which would presumably give good results consists of a copper cylinder about 10 cm. in diameter extending to within about 3 cm. of the upper and lower surfaces of the liquid. In its axis is a shaft carrying a propeller screw which in rotating sends a column of liquid up the tube. At the upper end of the shaft is fixed a horizontal pulley which is turned by a movable belt. The liquid would leave the upper end of the tube with a whirling motion and spread out in all directions.

The second end is secured by employing an expansible liquid of small heat capacity. The table below gives a list of some of the available liquids with a comparison of the properties desired.

	Alcohol	Benzine	Toluene	Kerosene	
Specific Heat	16°-40° .612	6°-60° .4194	@ 65° .4905	.5	Approximately.
Boiling point.	78°	80°	110°	140°	"
Cubical coefficient of expansion.	0°-40° .001122	30°-35° .001238	0°-100° .001206	.0009	"
Price per gallon.	\$2.25	\$	\$4.00	\$0.10	

The desirable properties are high boiling point, large coefficient of expansion, small heat capacity and low price. Toluene is probably the best compromise, while kerosene has a decided advantage in boiling point and price.

The third point may be secured by diminishing the diameter of the copper tubing in the thermal bulb. This, however, must not be carried so far as to reduce the volume of the expansible liquid too much or to introduce so many joint as to retard the action of the regulating device. Another cause for the lag in the action of the apparatus is the fact that the expansion of the copper tubing occurs before that of the alcohol.

The proper heating current is also a matter of importance. To maintain a certain temperature one should employ a current only slightly greater than that needed to produce this temperature.

The electrolytic method of heating makes possible a better distribution of heat, since it is generated in all parts of the liquid while in the case of wires immersed in oil the heating is confined to one plane in each of the four sides of the vessel, and hence the efficient circulation depends almost entirely upon the stirring device.

The Beckman differential thermometer is very convenient to use, but its disadvantage is the sticking of the mercury column in the tube unless the latter is tapped and hence small changes of temperature pass unnoticed. The platinum resistance thermometer,as described by Calendar (11),is much to be preferred as it may be constructed so as to detect very small differences in temperature and these may be indicated quickly by the deflection of the galvanometer.

The tests made on this apparatus have shown a lag in its action. This is more pronounced in the case where the heating is done by sending a current through wires in the oil bath than when the current is sent through a salt solution. When this method of heating was employed the makes and breaks occurred much more frequently. A more effective stirring device will also tend to decrease this lag and it may be necessary to reduce the diameter of the copper tubing in the thermal bulb.

The following preliminary tests were made on the two forms of heating arrangement.

The oil bath was heated up to 36.8°, the Beckman thermometer indicating 4.575°. Below is the result of the test.

Time	Temp.	Reading of Beckman Ther.	Remarks.
4:12	36.8°C	4.575°	Circuit broken and made.
4:18		4.490°	Current on.
4:20		4.480°	Current off.
4:35		4.550°	5 or 6 interruptions since 4:35.
		Second part of test.	
5:10	37.4°C	5.205°	
5:15		5.195°	Alcohol escaping at C fig.VII.
5:19		5.250°	
5:26		5.270°	
5:27		5:410°	Regulator readjusted.
5:31		5.365°	
5:36		5.390°	Current off, alcohol escaping.
5:42		5.420°	6 makes and breaks.
5:47		5.325°	Mercury pushed out of tube at t fig.VII.
5:50		5.290°	Set again.
5:54		5.340°	Makes and breaks every ten seconds.

A second test was made by heating up the salt solution by means of 10-ampere current. When the highest temperature which the current could produce was attained the cap C in fig.VII was screwed down and the solution kept stirred vigorously. The temperature was 75° and no change was noted during the time of the test which extended over one hour and fifteen minutes.

The thermometer, however, could only be read to tenths as no better instrument was available at the time. The makes and breaks succeeded each other at intervals of not more than two or three seconds while at times they were as frequent as 2 or 3 per second. This shows that the heat changes take place much more rapidly than when the heating is done by wires in oil. Thus this method of heating seems at the outset to give the best results. The leakage of alcohol at C was stopped by making the cap solid.

The lag noted was shown by the mercury column rising in the glass tube in fig. VII after the current was cut off and by its continuing to fall after the circuit was closed. This applies to the first test.

It was found that a current of 1 ampere was sufficient to carry the oil bath from room temperature (25°) to 40°, 5.5 amperes will carry from 25° to 60° while a current of 10.5 amperes will heat the salt solution from 25° to 75°.

The current used in the first test was much greater than needed and this may account for some of the lag noted.

There are several changes that remain to be carried out. The box containing the wires in oil is incomplete. A constant temperature chamber 21x21x45 cm. is to be introduced within the copper tubing of the thermal bulb. This would decrease the volume of oil to be heated and would enable it to be stirred with the device at present employed. The suggestion for improvement of stirring apparatus on pages 12-13 would also tend to decrease the lag.

It may be necessary to reduce the diameter of the copper tubing of the thermal bulb so that the alcohol may more quickly respond to heat changes on the exterior.

Summary of Testing.

From the various tests which the author has made on the apparatus constructed as described above, the following conclusions may be drawn:

I. That there is a small lag in its action. This may be decreased,

(1) By the addition of a constant temperature chamber thus reducing considerably the volume of oil and making a more efficient circulation possible.(

(2) By making the improvements suggested in regard to the paddles for stirring or introducing the second design of stirring apparatus.

(3) By using in the thermal bulb a liquid of smaller heat capacity.

(4) It may be advisable also to reduce the diameter of the tubing in the thermal bulb in order to facilitate heat changes.

II. That the electrolytic form of heating gives the best results for the following reasons:

(1) The heating is done in all parts of the liquid thus securing a more uniform distribution of heat.

(2) Since the salt solution is less dense than the oil it is more easily stirred.

(3) The mechanism of the heating arrangement is simpler and hence not so likely to get out of order.

(4, The bath being a salt solution it is cleaner and more easily handled.

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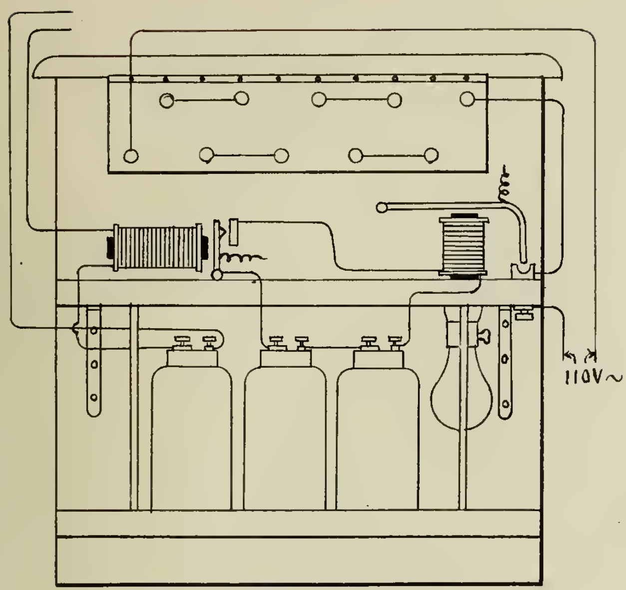


Fig. I.

Front Elevation.

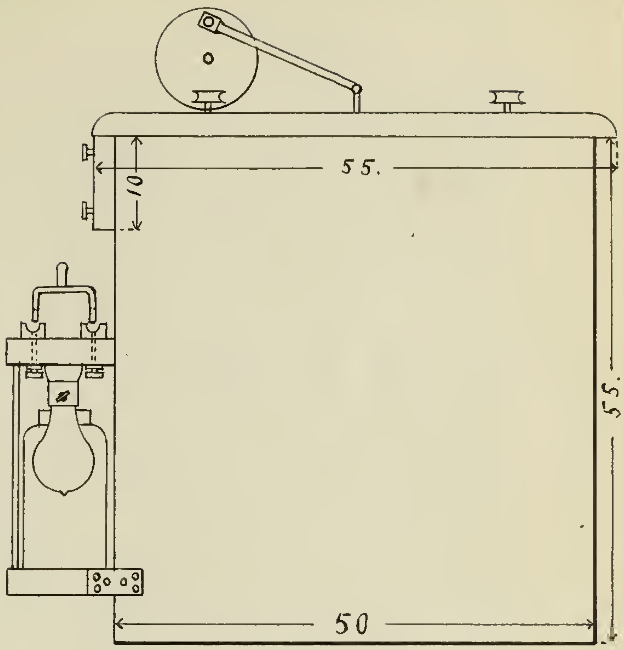


Fig II

Side Elevation.

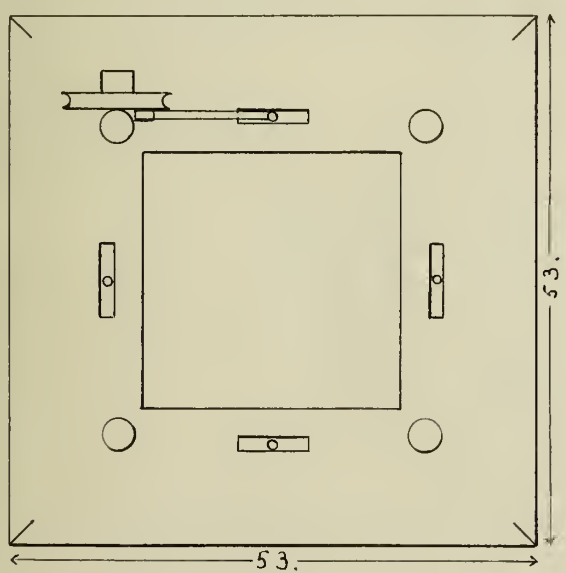


Fig. III.

Plan - Cover on.

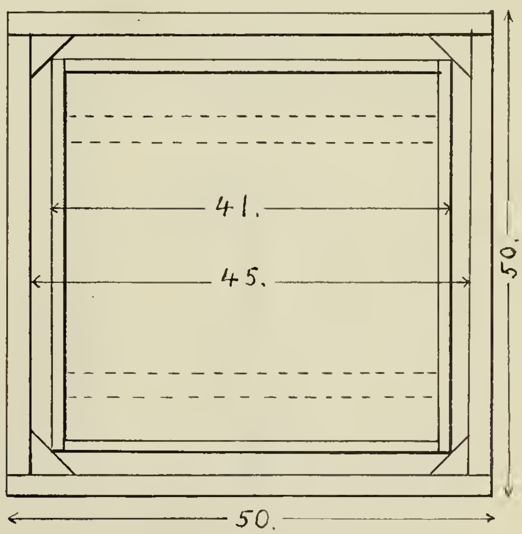


Fig. IV.

Plan - Cover off.

Scale $\frac{1}{20}$" = 1 c.m.

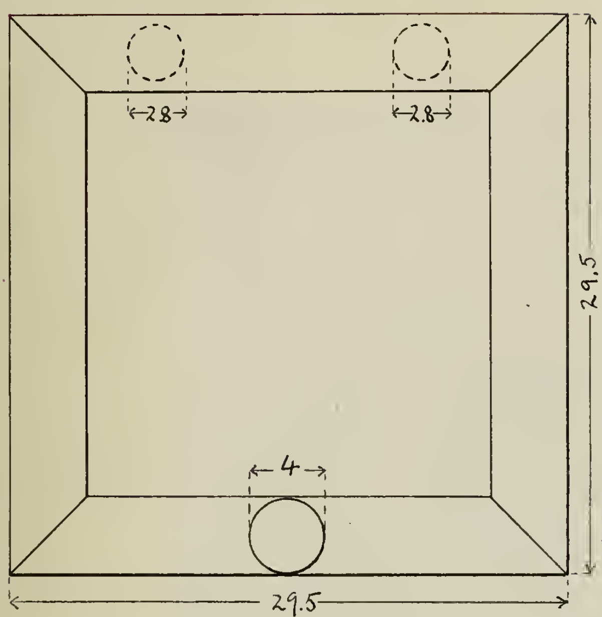


Fig. V.
Thermal Bulb.
Plan.

Scale $\frac{1}{15}$" = 1 c.m.

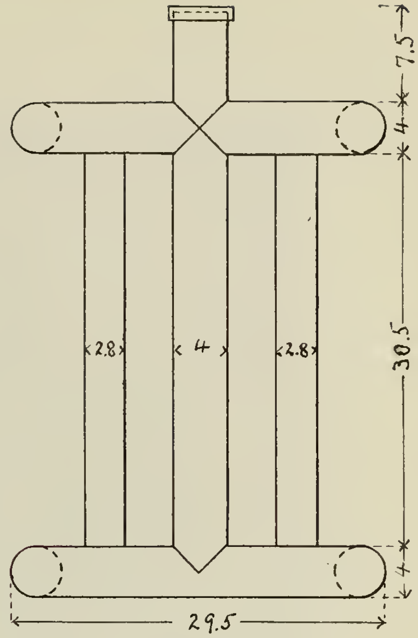


Fig. VI
Thermal Bulb.
Elevation.

Scale $\frac{1}{20}$" = 1 c.m.

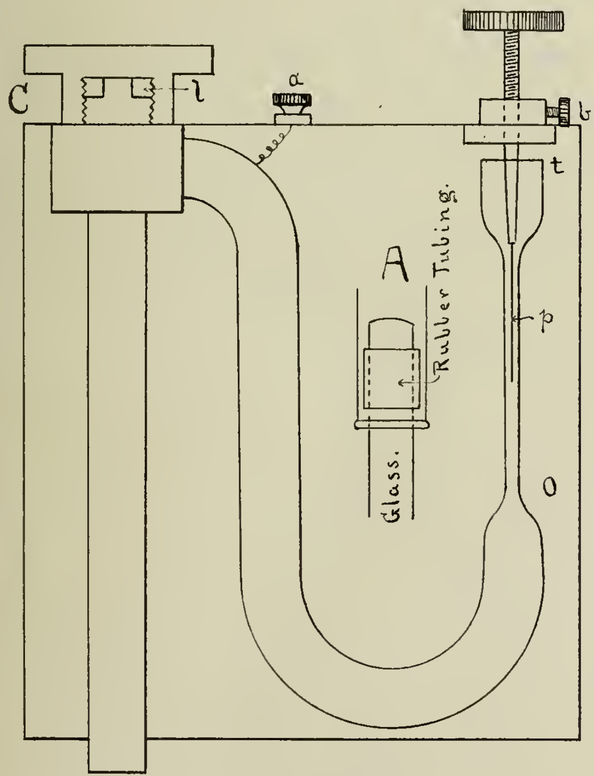


Fig. VII
Regulating Device.

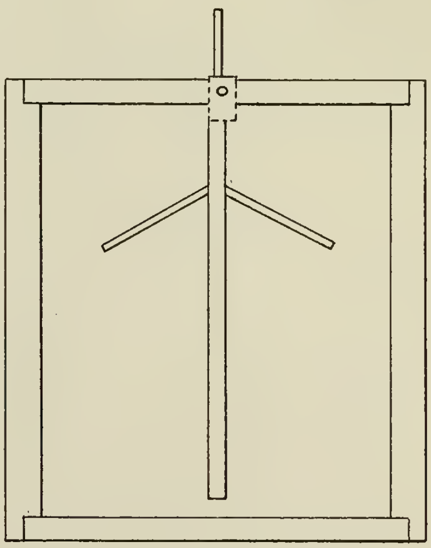
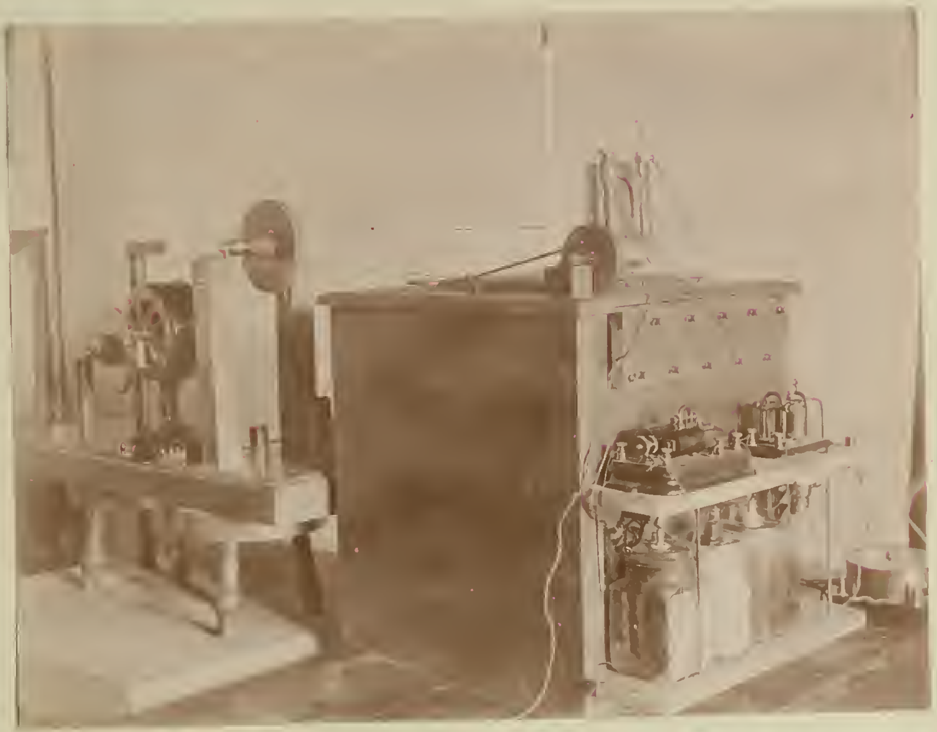


Fig. VIII

Scale $\frac{1}{20}$" = 1 c.m.



This photograph represents the thermostat as designed by the author and finally set up. On the left is the fan motor for running the stirring device. Above is seen the Beckman thermometer and the regulating device. In front are the relay, electro-magnet,cells and other electrical connections.